Learning Frameworks for Future Infrastructure Provision

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Abstract

The vast scale of global infrastructure spending over the next 25 years, and the opportunities created by the new disruptive technologies, ought to generate profound benefits through realising new societal ambitions. A key challenge for infrastructure providers is to ensure that their future understanding and capabilities are in harmony with the evolving complexity and scale of the task. Radical solutions require a radical collective mindset and a radical reframing of infrastructure provision. Mindset change and new capabilities develop only through learning. This paper argues that radical change depends on making explicit and improving the individual and collective learning across all actors, including citizens as co-producers and users, and that the infrastructure sector needs to reframe itself around explicit learning to achieve this outcome.

Key Words

Learning Journey, Learning Power, mindset change, collaboration, standards, complexity,

Paper

Introduction

The provision of economic infrastructure is at a propitious transition point; the emergence of a more holistic understanding of infrastructure and its purpose, allied with a set of major disruptive technologies including big data, machine learning and artificial intelligence, offers the potential for creating radical ways for infrastructure to help satisfy the growing complexity and scale of societal needs. Increased awareness of local and global environmental impacts, coupled with unsettled economic and political contexts, particularly the slow recovery from the global financial crash of 2008 and its ramifications on the lives of ordinary citizens, are stimulating dissatisfaction with business-as-usual approaches. The latter are increasingly seen as causes of problems rather than solutions to the societal challenges.

Such considerations have led to the articulation of significant progressive global and local societal ambitions, in which infrastructure must play a crucial role. The United Nations Development Programme's Sustainable Development Goals[1] set out a high-level requirements framework, spanning national, regional and global settings to facilitate, amongst other goals, the eradication of poverty and the establishment of

[1] United Nations. Transforming Our World: The 2030 Agenda for Sustainable Development, A/RES/70/1 (2015)

sustainable urban living. An example at local scale is the city of Bristol's 50-year Resilience Strategy[2], which sets out the ambition: *"By 2066 Bristol is a flourishing, welcoming city which inspires confidence in local and global investors and our success is shared by all"*. These examples are indicators of a strengthening appetite, and a timely opportunity, for imaginative, radical and more holistic societal solutions across the scales, from local to global. Future infrastructure provision has a crucial role to play in these radical solutions, but to do so the philosophy, mindset, purpose and methods of future infrastructure providers must be similarly radical – business-as-usual will not deliver radical change.

The financial scale (and opportunity) of these kinds of societal ambition is huge in infrastructure terms alone. The Global Infrastructure Hub suggests that annual global infrastructure spending should be 3.5% of global GDP ($3.7 trillion per year) amounting to $97 trillion by 2040[3]. The UK National Infrastructure Delivery Plan (2016)[4] envisages a UK infrastructure spend pipeline of £425 billion to 2021 and beyond.

Three core challenges are associated with this scale of spending: (i) maximising the value captured; (ii) minimising the cost, and (iii) persuading the citizen to pay for it. Effective solutions to these challenges depend on our knowledge and holistic understanding of how real infrastructure works, at both the asset and system scale, and of the societal and citizen benefits that accrue from it. Gaps in our knowledge and understanding (epistemic uncertainty) lead us to increase conservatism and costs, whilst also inhibiting innovation and value capture due to the perceived risks being too great. Reduction of epistemic uncertainty depends on the quality and scope of our learning and the consequent extension of our capabilities to deliver successful infrastructure. Modern infrastructure provision relies heavily on global supply networks that engage vast numbers of people in direct and indirect collaboration. Effective collaboration depends on shared mindsets, connected knowledge and capability, and common purpose, all of which are outcomes of our individual and collective learning. Experience from the education sector shows us that learning is more effective if it is made explicit and is structured around sound principles. However, in current infrastructure provision approaches, learning tends to be implicit and not structured on such principles. The learning and practice is connected by standards, but these generally make scant reference to learning. Indeed, it can be argued that current standards inhibit learning and innovation, since deviation from the standards is seen to be too high risk. Standards thereby tend to embed business-as-usual thinking into the infrastructure provision culture.[5]

We are on the cusp of the adoption of new technologies that business-as-usual thinking will find difficult to accommodate. Low cost sensing technologies, ubiquitous reconfigurable and intelligent digital communications networks, the Internet of Things, big data, automatic control, machine learning and artificial intelligence techniques will provide unprecedented ways for us observe in detail and learn about the performance of infrastructure assets and systems. As the vast amounts of data and information will be beyond the capacity of the human brain to process, we shall become increasingly reliant on machine learning and artificial intelligence technologies to do the processing for us and to point us towards key

[2] Bristol City Council. Bristol Resilience Strategy (2016)
[3] Global Infrastructure Hub. Global Infrastructure Outlook, ABN 46 602 505 064,(2017)
[4] Infrastructure and Projects Authority. National Infrastructure Delivery Plan 2016-2021, (2016)
[5] v.d.Tann, Angelino, Crick, Taylor. Rethinking Design Standards as Learning Frameworks, ICIF White Paper (2017)

insights. Future integrated design and operational environments will increasingly incorporate AI bots that will recognise and anticipate issues of interest to us, will acquire and analyse data automatically, and will offer timely suggestions and information that will facilitate our learning, decision making and action. Just as the introduction of personal computers in the 1980s relieved engineers of the burden of routine manual calculations and released their cognitive powers for more creative activities, so will the advent of AI enabled tools relieve future infrastructure providers from routine manual functions, enabling them to extend their cognitive and creative capabilities and to apply their imagination with greater impact. However, this beneficial outcome depends on us learning how to use these tools to best effect and on adapting our mindsets and methods accordingly.

In aggregate, the scale of infrastructure spending over the next 25 years, and the opportunities created by the new disruptive technologies, ought to generate profound benefits through realising the new societal ambitions. A key challenge for infrastructure providers is to ensure that their future understanding and capabilities are in harmony with the evolving complexity and scale of the task. Radical solutions require a radical collective mindset and a radical reframing of infrastructure provision. Mindset change and new capabilities develop only through learning. This paper argues that radical change depends on making explicit and improving the individual and collective learning across all actors, including citizens as co-producers and users, and that the infrastructure sector needs to reframe itself around explicit learning to achieve this outcome.

The citizen as the key co-producer in infrastructure provision

The citizen is at the heart of both the UNDP Sustainable Development Goals and the Bristol Resilience Strategy, not just as the end beneficiary of the outcomes but, crucially, as the key actor in the attainment of the outcomes. A flourishing city only flourishes if its citizens are flourishing. A citizen survives and ultimately flourishes through his or her own choices, actions and behaviours[6]. Most of our behaviours and associated capabilities are learned through our life experiences; thus, the more adept we are at learning and developing beneficial behaviours, the more likely we are to flourish.

A key characteristic of human beings is our ability to combine our efforts through collaboration to achieve mutual benefits – we have learned that we can achieve more by working collectively rather than individually. Our social conscience often drives our willingness to offer disproportionate effort to fellow citizens who are less able to contribute themselves; in the long-term there is latent value in doing so for we might need to benefit from reciprocity in the future. If we experience benefit, we are more likely to exchange our efforts and resources to receive the benefit, i.e. be more willing to pay for it in one way or another.

Successful collaboration depends on successful collective learning that establishes common purpose and extends and links our capabilities to plot and navigate a learning and action journey to a destination that fulfils our purpose[7]. The uncertain nature of the real world requires this journey to be adaptive as reality

[6] Baars & Gage. Fundamentals of Cognitive Neuroscience, Elsevier, ISBN 978-0-12-415805-4 (2013)
[7] Crick, Huang, Godfrey, Taylor, & Carhart. Learning Journeys & Infrastructure Services. ICIF White Paper (2017)

unfolds and our potential futures, including our purpose, are re-anticipated in the light of our new experiences. Through our continuous learning, we can extend our resourcefulness and confidence to flourish in the face of uncertainty[8].

When a citizen uses the service of an infrastructure, they have decided (consciously or sub-consciously[9]) that it is beneficial to do so. The decision-making literature offers many approaches for assessing the value of one option against others[10]. The literature also often tends to assume that once the best (i.e. perceived most beneficial) option has been decided on, the actor automatically enacts the chosen option. However, the Authors' ongoing research into customer behaviour in the infrastructure sector, particularly consideration of switching behaviour in the utility and banking sectors, suggests that knowing the best option is only one necessary condition. Many customers often know (or at least suspect) that a better option is available from a different supplier but they still choose not to switch. Our developing research indicates that if citizens are to avail themselves of the benefits of infrastructure, they need to: (i) understand the benefits that the infrastructure can enable them to accrue; (ii) understand how to use it; (iii) have sufficient trust in it being able to deliver the quality of enabling service they need; and (iv) have sufficient motivation to realise the benefit by using the infrastructure. Each of these conditions is necessary but not in itself sufficient. All four conditions must be satisfied for the citizen to move from decision to action. Such understanding, know-how, trust and motivation all arise from the citizen's learning.

This theory implies that infrastructure providers need to support the citizen's learning if the citizen is to extract maximum benefit from the infrastructure service (and be willing to pay for it). The theory further implies that if citizens have been involved in the conception and delivery of the infrastructure, and thereby have been involved in the collective learning, they are more likely to develop the required secure understanding, know-how, trust and motivation. In doing so, they are more likely to anticipate the services they actually need and want, and to understand the benefits they will accrue from them. They will also be able to share these anticipations and their contextual understandings (personal, community, geographic, behavioural etc) as part of the collective learning with the wider provision team, who in turn will develop and benefit from a more dependable and richer understanding that should underpin more effective solutions. This 'co-production' approach, with citizens being active participants in the conception and provision of solutions, has gained significant traction in several fields (e.g. health)[11]. Its success is dependent on the efficacy of the individual and collective learning. It appears that infrastructure provision could gain much from this citizen outcome focused, co-production approach. The Authors' ongoing research is exploring this proposition.

[8] Beigi, S. Mindfulness Engineering: A Theory of Resilience for the Volatile, Uncertain, Complex and Ambiguous (VUCA) World. PhD thesis, Bristol University (2015)
[9] Kahneman, D. Thinking, Fast and Slow. Farrar, Straus and Giroux (2011)
[10] Saaty, T. Decision Making with Analytic Hierarchical Processes. Int. J. Services Sciences 1(1) (2008)
[11] Boyle & Harris. The Challenge of Co-Production. NESTA, ISBN 9781848750692 (2009)

The value in re-thinking the purpose and provision of infrastructure from an active citizen perspective

In his work on ecological system dynamics, Odum[12] explained the desirability for collaboration in energy terms. For a living being to exist, it must acquire enough energy and matter that it can convert into useful work and body structure so that it can survive and procreate. For an individual of a species to survive independently, it must be disproportionately powerful in its ability to compete for sufficient energy and matter. For example, independent predators at the top of food chains might be much bigger, faster, more agile or intelligent than others, but there is often only ecological space for a few of them. It is difficult for highly independent beings, and thereby their species, to survive. Most species have evolved collaborative behaviours (in some cases symbiotic relationships with other species) to share the effort of survival, often creating elaborate physical and sometimes social infrastructures that enable them to do so. Human beings are good examples; we create elaborate physical infrastructure systems (e.g. cities) and social infrastructure systems (e.g. legal, financial, political, cultural, educational, health etc.) that enable us to share our efforts in acquiring and transforming sufficient energy and matter to survive. (Perhaps we are flourishing when we no longer perceive survival as an effort?). In human constructed infrastructures, energy and matter are carried in many forms, including fuel, food, materials, products, information, and, of course, human beings.

Odum's theories are an interesting lens through which to perceive the purpose and functioning of infrastructures; in essence, they are the means we create to enable us to acquire, transport, transform and utilise sufficient energy and matter upon which we depend for our survival as individuals and as a species. For example, through this lens, the primary service offered by the Clifton Suspension Bridge is the safe carriage of bundles of energy and matter (i.e. people and their vehicles) across the Avon Gorge. The primary services of a sewage treatment plant might be regarded as the acquisition of human waste (a carrier of energy and matter) and its transformation into useful energy (e.g. methane) and matter (e.g. fertilizer). Each of these service examples delivers direct and indirect benefits to the citizen as a user and as a beneficiary of the wider societal activity that the service connects to. In realising these benefits from interacting with the infrastructure services, citizens are being active and motivated users. Conscious comprehension of these benefits, of how they arise and how they enable other benefits, is likely to increase a citizen's willingness to pay for them. Such comprehension is an outcome of the citizen's learning and experiences. However, it seems, for most citizens, infrastructure services are taken-for-granted and their comprehension of the benefits resides in their sub-conscious minds; it tends only to be elevated to their conscious minds when the infrastructure services fail (as John Oliver humorously pointed out[13]). Species survival depends on individual survival, thus we should direct infrastructure provision towards delivering the services that individual citizens need, including those services that enable them to collaborate and contribute their efforts to mutual benefit; society as a whole will then benefit.

[12] Odum, H. Environment, Power & Society for the 21st Century. Columbia Univ Press (2007)
[13] Oliver, J. Infrastructure: Last Week Tonight with John Oliver (HBO). https://www.youtube.com/watch?v=Wpzvaqypav8. Accessed 10/08/17

Framing future infrastructure provision around learning

There is no doubt that collaborative learning takes place in the infrastructure provision sector at present – innovation and development would not occur without it. However, in general, the learning is implicit and not recognised. Organisational learning theories[14] might be applied by particular actors on particular projects, but the overall cultural and methodological framing of the infrastructure sector does not make learning explicit nor require it to be. Modern codes of practice and standards make little explicit reference to learning as a core engineering activity; instead they tend to resort to prescriptive procedures that are distillations of experiences of successful practice but have vague links back to the generative learning[15]. Few engineering undergraduate programmes have formal courses on individual and collective learning, or cognition and behaviour, and how these impact engineering practice. This prompts a question: If the education of the infrastructure talent pipeline leaves its talent ignorant of learning, and the framing of the sector culture continues to render learning as implicit, will we be able to deliver the scale of imaginative and radical change that future infrastructure provision needs?

Evidence from school settings shows that learners learn more effectively if they know how to learn and develop their learning skills and to make their learning explicit. Deakin-Crick et al[16] have identified sets of learning attributes, and ways of measuring them, that constitute what they term a person's 'Learning Power' profile. The attributes include a set of 'active' dimensions (*Mindful Agency*, *Creativity*, *Curiosity*, *Sense-making*, and *Hope*), a set of 'relational' dimensions (*Sense of Belonging*, and *Capacity to Collaborate*), and finally a measure of O*rientation towards Risk and Uncertainty*, and *Willingness to Adapt and Change*. The learning power attributes can be improved by purposeful individual learning, while a team's collective learning power can be improved by bringing together people with complementary learning power profiles. Deakin-Crick et al's research has shown that by explicitly developing learning power, the quality of learning outcomes improves, as does the motivation to do so.

Deakin-Crick et al's Learning Journey is a '*metaphor to describe the process of changing and adapting profitably in moving towards a specific purpose or outcome*'[17]. It has four measurable sub-processes: *Forming Identity and Purpose; Generative Learning Power; Structuring Information; Producing Value*. These form a pathway from purpose to performance but are each continuous and interactive processes as the learning progresses. They underpin an iterative learning cycle that loops over *Choose My Purpose*, *Diagnose and Plan*, *Do the Job*, and *Measure and Evaluate.* Each stage and iteration of this learning cycle draws upon and extends the four learning journey sub-processes. The latter can be generated and drawn upon by both the individual and the team, thereby supporting connectivity and collaboration. The processes are present to some extent, but largely implicit, in current infrastructure practice. For example, standards and design tools generally support forming purpose to some extent, will offer various ways of

[14] Cacioppe & Edwards. Seeking the Holy Grail of Organisational Development. Leadership & Organization Development Jrnl, 26(2) 2005
[15] Angelino, Taylor, & Denton. What Should Future Design Standards in the Construction Industry Look Like? Proc Int Conf on Smart Infrastructure and Construction, (2016)
[16] Deakin Crick, Huang, Shafi & Goldspink. Developing Resilient Agency in Learning. Brit Jnl of Edu Studies (2015)
[17] Crick, Huang, Godfrey, Taylor, & Carhart. Learning Journeys & Infrastructure Services. ICIF White Paper (2017)

structuring and sharing information, and will identify or support the design of processes that will produce value, but rarely will they support the generation of learning power – the last is the crucial gap that needs to be filled. The learning cycle above is similar to the Deming 'Plan-Do-Report-Review' quality cycle, and to Alastair Smith's Accelerated Learning Cycle[18]. Learning cycles complement the neurological processes that build and secure the neural networks that hold our knowledge, understanding and capabilities in our brains[19]. Each time the neural network is fired, new links between neurons are formed at the synapses, the bonds between existing links are strengthened, and the speed of signal transmission along the dendritic links between neurons increases. It is natural for us to learn iteratively.

The learning process can be viewed as three nested learning loops, each loop generating a meta-level mental model above the previous loop[20].

'Single loop learning' activates the inner-most loop, which simply activates an established model; it is similar to an engineering control model where the control equations are fixed and the parameters are adjusted though feedback from the actual system performance to try to make the system match the target performance. In learning terms, this might be described as '*Just doing it*'. In terms of the framing of infrastructure provision, this might be interpreted as '*business-as-usual*'.

Reflexive learning activates the second loop. In 'double loop' learning, reflection on the single loop outcomes leads to change or adaptation in the architecture of the working model. In control terms, this is analogous to changing the structure of the control equations, again with the aim of matching the actual system performance with the target. In learning terms, this might be described as '*Learn to improve*'. In terms of framing infrastructure provision, this might be interpreted as the changing of the framing architecture itself (e.g. by introducing a Learning Journey framework), as the existing architecture is perceived not to deliver adequate performance.

Reflexive learning relative to the second loop activates the third loop. 'Triple loop' learning transforms the world view or mindset that frames the whole problem and the overall purpose. The outcome from the double and single loop learning might lead to the realisation that the world is not as you thought it was or that your previous high level purpose was not in fact beneficial to you. It might cause you to adjust your core values. The UNDP Sustainable Development Goals and the Bristol Resilience Strategy might be regarded as partly articulating new world views that have risen from reflecting on the perceived failures of the current order. Citizen discomfort with the impact of the financial crash and a consequent desire for transformative change might be viewed as an outcome of their triple loop learning.

The third loop can be seen to be important from a complexity point of view. We recognise now that our world is a complex, non-linear, system of systems[21]. As such, new states of transient equilibrium can

[18] Smith, A. Accelerated Learning in the Classroom. Bloomsbury , ISBN 9781855390348 (1996)
[19] Baars & Gage. Fundamentals of Cognitive Neuroscience. Elsevier, ISBN 9780124158054 (2013)
[20] Tosey, Visser & Saunders. The Origins and Conceptualizations of Triple Loop Learning. Management & Learning 43(3) 291-307 (2011)
[21] Carhart, N. Evidence for the Value of Systems Approach to Infrastructure Planning, Delivery and Operation, ICIF White Paper (2017)

emerge, for example global warming or the emergence of new geo-political power groups. These new states mean that the world is no longer as it was and that we need to re-align our world view, and possibly our values, with the new reality and to refresh our anticipations of the future. This might change our purpose and require new means to achieve it. If we are not conscious of the third learning loop, and do not have the concomitant learning power to change and adapt, then we will be insensitive to this scale of change and will be ill-prepared to deal with it. The anthropological record holds many examples of communities that are now extinct because they were deficient in triple loop learning, and the mindsets and actions that flow from it, and were unable to adapt to profound contextual change.

The work of the psychologists Graves, Beck and Cowan offers an interesting perspective of this mindset development and transformation[22], entitled 'Spiral Dynamics'. They postulated that our archetypes of world views develop in sophistication as humankind progresses. They called these mental model archetypes 'value memes'. They postulated that humankind has so far established eight levels of value meme, denoting each with a colour. The highest, 8th level, Turquoise, represents a holistic view of the world within its cosmic setting and the associated universal forces and patterns. The 7th level, Yellow, represents a systemic view of the world with its emergent properties and boundary essentially the Earth. They further postulated that most people operated at a 4th level (Blue - Authoritarian) or 5th level (Orange – Entrepreneurial) mindset, which represent reductionist, rationalist and simplistic cause-and-effect views of the world. The Spiral Dynamics model suggests that a person can operate at any world view level up to the highest level they have so far attained, and will choose a value meme suited to the task in hand.

Whilst the Spiral Dynamics model is contentious in many eyes, it is nevertheless a useful prompt for us to recognise that the way we currently frame infrastructure provision is shaped by the mindsets and world views of those people who devised its architecture and led its application. In Spiral Dynamics terms, these people are likely to operate at levels 4 and 5. If we accept that radical re-framing of future infrastructure provision is needed, then perhaps we need to start at least with a 7th level, Yellow, mindset.

Conclusions

A successful infrastructure system is an outcome of the collective learning and actions of the people who create, operate and use it. A reasonable hypothesis is that explicit attention to learning and learning power is likely to make the infrastructure provision team more effective and lead to better solutions.

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[22] Beck & Cowan. Spiral Dynamics, (Blackwell, ISBN 155786-940-5 (1995))